Lessons Learned on Bonneville Dam Juvenile Surface Bypass System Design

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Abstract.

In March of 1995, The National Marine Fisheries Service issued a Biological Opinion under the Endangered Species Act that outlined fish guidance efficiency requirements for the Columbia and Snake rivers. The Opinion stated that the goal for fish passage improvements would be 80 percent Fish Passage Efficiency and 95 percent passage survival at each dam. Through research, extensive literature review, and past prototype tests, fishery biologists and engineers had come to the conclusion that surface collection and bypass technology may assist in meeting these goals. The Bonneville Project, on the Columbia River was studied extensively for application of this technology prompting the Biological Opinion of 2000 directive at the Bonneville Second Powerhouse (B2): "The Corps will develop and implement a surface bypass corner collector…" and assuming positive results from concurrent investigations and research, "design and construct a corner collector system by 2004…". The Bonneville second powerhouse Corner Collector (B2CC) is currently under construction. This multi-year study embarked on a relatively new field of high flow outfall design for fish passage that required the participation of several National and State resource agencies (NMFS, CRITFC, USFWS, BPA, ODFW and WDFW), multiple AE Contractors, research entities such as ERDC, and aggressive schedules to complete. The hydraulic modeling elements were both exciting and challenging and included physical models at 1:30, 1:40 and 1:100 scales as well as numerical models. This paper summarizes some of these hydraulic elements as well as some of the more compelling lessons learned in the process.

Background.

The abundant salmon resources within the Pacific Northwest Region have declined over the years. This decline has aroused much public interest and concern. The inclusion of regional salmonid species to the growing list of Federal threatened and endangered wildlife prompted more specific action on the part of the National

Marine Fisheries Service (NMFS). In 1995, NMFS presented a Biological Opinion Document that outlined an ambitious multi-year plan to save these important fisheries resources.

One of the focus areas to this plan was to increase survival of migrating juvenile salmonids at the United States Army Corps of Engineers (USACE) Lower Snake and Columbia River hydroelectric projects. Along with the impacted resource agencies, USACE Portland and Walla Walla Districts developed several concurrent programs designed to research, test and implement state-of-the-art concepts in juvenile fish passage in an effort to increase passage efficiency and enhance juvenile survival through the lower Snake and Columbia Rivers. The intent of undertaking concurrent programs was to quickly determine several potential alternatives, evaluate them, and eventually implement the plan(s) with the most promise.

The Portland and Walla Walla Districts explored several concepts including: surface oriented collection and delivery systems (surface flow bypass), dissolved gas abatement, juvenile screen bypass systems and "fish-friendly" turbine design. The concept of surface flow bypass assumes that in general, juvenile salmonids have some preference to remain surface oriented along their downstream passage route. Wells Dam (a hydrocombine facility) on the upper Snake River has had success with surface oriented entrances attracting juvenile salmonids to pass the dam via the spillway rather than through the turbine entrances.

One of the earliest products of the surface flow bypass research program at Portland District were alternatives studies for all three major dams on the Lower Columbia River including: Bonneville first powerhouse (B1), Bonneville second powerhouse (B2), The Dalles Powerhouse, John Day Powerhouse and the spillways at each project. Surface flow bypass investigations at Bonneville Dam resulted in the development of several surface flow bypass alternatives at the B2 (Harza and ENSR, 1996). From these alternatives, a corner collector prototype was selected for further development at the B2 (INCA et al., 1997). In the NMFS 2000 Biological Opinion, the development, design and construction of a surface bypass corner collector at B2 became a priority. The B2CC is currently in construction and scheduled for operation in spring of 2004. This paper summarizes some of the hydraulic design history of this facility and communicates the most useful lessons learned in the process.

History.

Bonneville Project is located approximately 40 miles east of Portland, Oregon, at River Mile 146.1 in the Columbia River Gorge (Figure 1). The Project consists of the first powerhouse (1938, hydraulic capacity 136,000 cfs) and navigation lock on the south shore, the second powerhouse (1982, hydraulic capacity 152,000 cfs) on the north shore and a spillway (capacity 1,600,000 cfs at EL 87.5 ft.) in between the two powerhouses. Early in the study process for surface bypass at the B2, it was recognized that the use of the existing ice and trash chute as part of the surface collection system had advantages related to cost as well as prototype testing. The existing ice and trash chute entrance is on the south side of the B2 forebay and has a history of anecdotal evidence that juvenile salmonids have entered the chute in large numbers during the fish passage season. Further biological field-testing verified that juvenile salmonids were in fact using the chute as a fish passage route (Batelle et al, 2001).

Figure 1. Bonneville Project on Columbia River, Oregon looking downstream. Structures from top of page to bottom (South to North): navigation lock, first powerhouse, spillway, and second powerhouse.

Transforming a structure designed for ice and trash into a viable juvenile fish passage route ultimately required multiple years of study, intense coordination with resource agencies and a collaborative effort among the disciplines of biology; hydraulic, civil, structural, and geotechnical engineering; and project management. There were three major components in the design of the B2CC production system: an intake to collect the fish, a transportation channel to take them downstream to an optimal release point, and an outfall that would allow safe entry into the tailrace. On the surface, this appears to be a simple task. However, early in the design process several issues surfaced regarding the major design components in the system:

- Maximizing the ice and trash chute flow to attract more fish results in flows through the system ranging from 4100 cfs to 5900 cfs under normal forebay operation. Previous experience in this large amount of fish laden flow has been limited. Even current NMFS smolt bypass criteria (NMFS, 1995) were not well suited for high volume (> 1,000 cfs) fish passage and outfall design. Proposed guidelines especially suited for high flow outfall location and design were developed utilizing existing criteria as well as a set of premises that required refinement and additional research (Johnson et al., 1999). Due to high regional priority to complete this project, the research that was undertaken to refine guidelines occurred concurrent to hydraulic analyses and design of the system.
- The existing chute entrance is a 15 ft. wide vertical slot opening located on a sill at EL 52 and is oriented at 45 degrees from the axis of the dam. Just downstream from the entrance slot, the chute drops to a floor at EL 29 ft. and makes a 32.5 ft. radius 45 degree bend to the right (looking downstream) approximately 25 ft. downstream of the entrance gate. There is a vertical headwall approximately 20 downstream of the gate that provides an overhead crossing of the upstream migrant transportation channel (UMT) that fish laden flow entering the slot must

clear. The primary design constraint for the entrance was to provide an entrance and channel transition that was acceptable to fisheries criteria and would fit within the existing geometry of the chute.

- The nature of the Bonneville tailrace presents significant challenges related to the outfall location, outfall design as well as the transportation channel design. The B2 tailrace first merges with the spillway flows at the tip of Cascade Island, and then merges with B1 flows further downstream at the tip of Bradford Island. There are a myriad of Project flow scenarios possible related to the individual needs and priorities of the two powerhouses and the spillway. Selection of an optimal outfall location is constrained by the need for the system to be fully functional under multiple likely operational scenarios.
- The Bonneville tailwater elevation is also highly variable. The range of potential tailwater elevation is about 28 ft. (EL 7 to EL 35 ft.). Outfall designs must meet fisheries criteria related to the interaction of the high flow outfall flow with the receiving water characteristics for the full range of potential conditions. Proposed guidelines address restrictions on the maximum mean entry velocity, interference with adult migration, eddy formation, minimum ambient flow velocities, and mechanical fish injury and contact with the bottom related to the interaction of depth, and magnitude and trajectory of outfall discharge.

All of these issues needed to be studied. Ideally, a logical sequence of study might include: (1) development of new guidelines and criteria for a high flow bypass system through laboratory and field research, (2) sequential hydraulic design from the entrance to the exit. However, the region had a very aggressive schedule and strong desire to complete the project by 2004 (as stated in the 2000 Biological Opinion). Consequently, most aspects of the analysis and design were undertaken concurrently. The aggressiveness of the schedule left little flexibility or room for error in the modeling or design process. This often resulted in complex design problems that required immediate innovative solutions. Ultimately a hydraulically sound surface bypass system was designed (Figure 2). Below is a summary of hydraulic components and the modeling required for design. Following this is a list of recommendations gleaned from the lessons learned during the analysis.

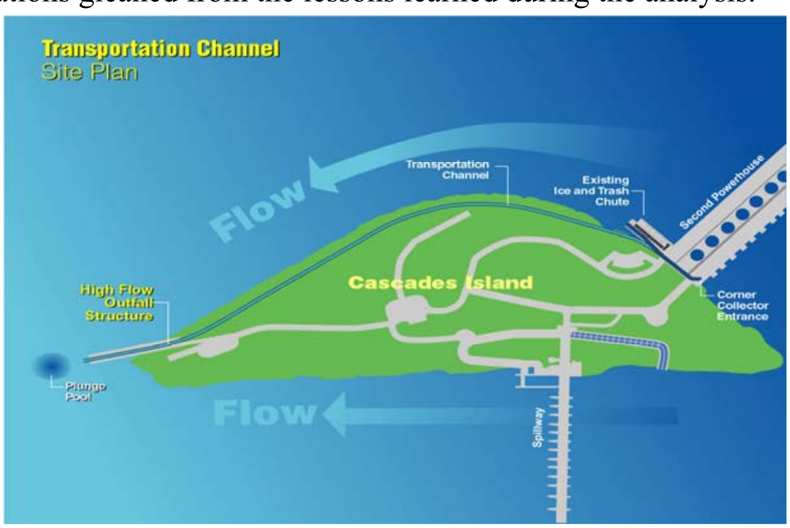

Figure 2. Components of the Bonneviile Second Powerhouse Corner Collector.

The Design.

The final design consists of three major components: the intake, transportation channel, and outfall as identified in Figure 2.

The Intake: The objectives for the intake design were to increase the entrance flow of the existing ice and trash chute and create a relatively benign fish passage route from the gate (EL 52 ft.) through approximately 220 ft. of the existing chute (EL 29 ft.) to where the new transportation channel would begin. The final B2CC design intake consists of the existing 15 ft. wide, rectangular ice and trash chute entrance with two modifications. The gate is modified to maximize the flow through the entrance, increasing the existing entrance depth by about 9 feet. In addition, a curved ogee shaped structure with a 10 ft. radius toe curve was designed just downstream of the entrance to create a smooth transition from EL. 52 ft. to EL. 29 ft. along 32.5 ft. radius 45 degree curve to the existing ice and trash chute floor while avoiding the overhead concrete beam from the UMT (Figure 3). A vertical fillet, attached to the inside of the curve downstream of the toe of the ogee was also needed to straighten the flow.

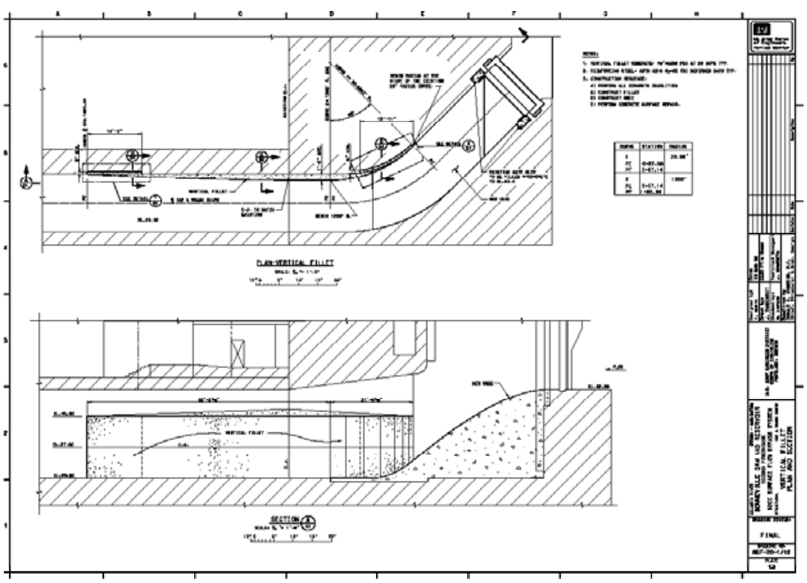

Figure 3. Ice and trash chute with proposed modifications including gate, ogee insert and vertical fillet (USACE Portland District, 2002). Flow is from right to left.

Hydraulic modeling consisted of utilizing a 1:40 scale physical model at the Engineer Research and Development Center in Vicksburg, Mississippi (ERDC) and 3D computational modeling at Pacific Northwest National Laboratory in Richland, WA (PNNL). Complex hydraulic conditions downstream of the ogee section occur due to the combination of high velocity, turning and superelevated flow. To minimize cross-waves and provide satisfactory water depths in the area downstream of the toe curve, a vertical insert was placed on the north wall of the chute.

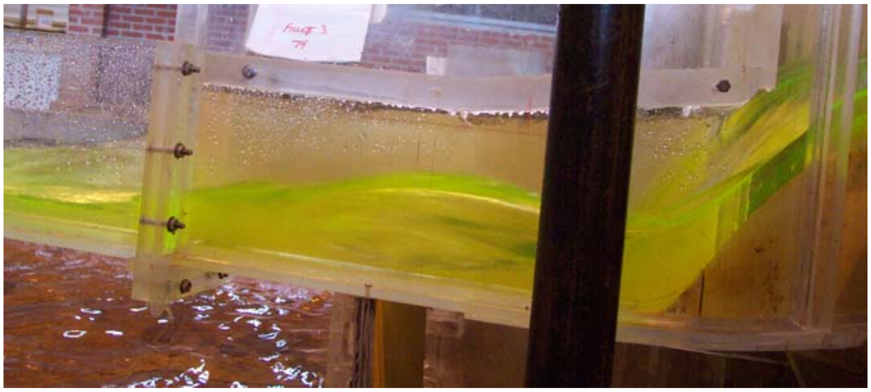

Figure 4. View of flow (right to left) on 1:40 scale physical model just downstream of entrance passing over ogee and displaying superelevation along outside of 45-degree bend. Note acrylic representing existing horizontal ceiling and overhead beam as design constraint.

The Transportation Channel: The transportation channel required some modification to the existing ice and trash chute floor and walls and the construction of additional channel to transport the juveniles safely to the new outfall location. Objectives again were to create a relatively benign fish transportation route from where it exits the existing ice and trash chute to the new outfall site. The new 15 ft. wide, rectangular, approximately 2800 ft. long and relatively flat channel (El 29 to El 16 ft.) was constrained upstream by the existing chute entrance dimensions/elevations and hydraulic conditions. The downstream end was constrained by the optimum location of the outfall exit (described below). A one dimensional HEC-RAS model of the transportation channel was built to provide water surface elevation estimates in the channel and the interaction of the flow in the channel with the varying tailwater conditions. This modeling highlighted the sensitivity of the channel to the selection of Mannings n. This resulted in very tight construction specifications for high velocity smooth concrete throughout the transportation channel. In addition, a numerical model of the tailrace was used to determine velocities acting on external walls of the transportation channel and outfall structure.

Outfall Location: Safe release of the juvenile salmonids into the complex tailrace at Bonneville required hydraulic design of a specific outfall "type" and the optimal siting for the juvenile outfall. The final outfall location was determined to be at the downstream tip of Cascade Island that separates the tailraces of the second powerhouse and the spillway. Biological design guidelines for location of the outfall addressed issues such as predators, areas of low flow and eddies, interference with adult migration and maximum flexibility with multiple Project operations. The final location was found through extensive observation of the far-field outfall flow egress of various outfall types on the 1:100 scale physical model of the Bonneville Project at ERDC. Several preliminary locations were investigated through observation of dye releases under several representative spillway and powerhouse operational combinations (Figure 5). Close collaboration between ERDC staff, AE contractors, Portland District personnel and resource Agency representatives was needed during this intensive 4-month period of modeling.

Figure 5. Example comparison of dye release for different ambient flow conditions on 1:100 scale physical model of Bonneville at ERDC. View looking downstream at confluence of second powerhouse and spillway for final outfall location.

Outfall Structure: The final outfall design is a 15 ft. wide rectangular channel cantilevered 10 ft. off the support structure approximately 400 ft. downstream of the tip of Cascade Island. The system discharges into an excavated plunge pool in the river channel. In addition to the above biological design guidelines for outfall location, further criteria addressed eddies or back-rollers in the outfall pool and plume, mean entry velocity, dissolved gas concentration, adult fish injury and receiving water characteristics that prevent mechanical fish injury and bottom contact. A 1:30 scale model at ENSR Consulting and Engineering, Redmond, Washington was used to investigate the near field outfall flow hydraulics for various outfall type designs including a vertical transition chute, a skimming outfall, and a cantilever with and without a plunge pool (Figure 6). Boundary conditions in the tailrace were obtained from the 1:100 scale model. Sensitivity modeling later determined that the 1:30 scale outfall jet near field behavior was not very sensitive to this upstream boundary condition. Determination of the shape utilized observation of the jet scour in movable bed material. Some of the data taken included bottom impact pressures along the centerline of the plunge pool; jet entrance cross-sectional area, and maximum jet entry velocity, shear stress and strain rates for a range of outfall flows and tailwaters (ENSR, 2002). Again, extensive observation and collaboration with the design team and agencies were necessary to come to a final decision.

Figure 6. Final plunge pool and outfall structure design on 1:30 scale model at ENSR, Redmond, Washington.

Lessons Learned.

An After Action Review (AAR) was conducted at ERDC in November of 2001. This review addressed only the hydraulic design portions of the project. Most of the following recommendations are derived from this AAR report (USACE, Portland District, 2001).

Scoping/Scheduling. The entire team needs to be involved early on in the scoping/scheduling of the study and agreement on the proposed schedule is needed prior to a commitment being made to the resource agencies. The schedule should accommodate potential changes by providing sufficient float time especially when non-traditional processes are used to investigate new ground. The scope should also define potential risks/rewards within the agreed to schedule.

Coordination. A definition of responsibilities among all team members (ie: Districts, AE's, and ERDC) must be established early on to avoid important issues or details from being overlooked. Participation and information transfer (ie: conference calls, VTC and web cameras) are needed among all players throughout the study especially when program decisions impact individual responsibilities/schedules. Additionally, frequent and early coordination between hydraulic and biological research activities is needed especially in a relatively new field without much design experience and/or when working under an aggressive schedule.

Concurrent vs. Sequential Tasks. Highly aggressive schedules and complex priorities from multiple players may require concurrent investigations when sequential investigations would be more appropriate. Resources may be overextended. Risks inherently increase and when they can be identified should be communicated in writing to all team members in a timely manner. Hydraulic modeling should occur early in the design process and ideally, design guidelines should be agreed to prior to model studies. If possible, design should occur from upstream to downstream rather than in concurrent segments in order to allow the flexibility to optimize on the entire system design. The most efficient and cost effective product is more likely found given a more engineered approach to study design. When this is not possible, hydraulic sensitivities must be established frequently for each design segment and an example "system" should be tested periodically to determine compatibility. Finally, the Design Documentation Report should precede Plans and Specifications phase to avoid limiting design options when/if "surprises" are revealed in the hydraulic modeling effort.

Model Verification/Quantitative Methods. Model verification procedures should be identified early for all model features. Accuracy of model flow features should be checked frequently and consistently throughout the study and not be circumvented for the sake of the schedule. ERDC, Districts, AE staff and biological researchers should continue to seek out ways to quantify performance criteria and results of modeling to reduce the subjective nature of observations. Once criteria are determined, a data collection effort should be designed that will support it.

Model Maintenance/Documentation. Routine physical model maintenance lists should be kept and funding be made available to keep critical models in reasonable condition. Extensive deterioration of the powerhouses on the 1:100 scale model (almost 20 years old) required intensive collaboration between ERDC and ENSR to construct/install and calibrate a new powerhouse within a very short timeframe. Model documentation can clarify procedures, techniques and model results and should be given equivalent priority to the modeling itself. Within an aggressive schedule it is tempting to shift resources from the documentation effort to a "higher priority" task, risking the loss of valuable information and quality assurance.

Other Quality Control Measures.

- A thorough investigation of previous knowledge related to the design/study at hand should be undertaken early.
- Major program decisions should not be based on simplified modeling techniques. Variables that could impact model results should be defined and evaluated for their affect in the model, before decisions are made. Then, follow-up confirmation should occur as soon as possible after program direction has been determined.
- Multiple hydraulic methods should be used whenever possible for comparison, sensitivity evaluation and validation of the primary hydraulic method.
- Determine model sensitivities at every step and communicate and document the risks of doing vs. not doing the analysis.
- Keep a running list of current design parameters, what model they were based on, when the model was run, what assumptions were made, what sensitivities were defined, and the risk of not refining or benefit of refining design parameter.

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